MEMORANDUM REPORT BRL-MR-3840

BRL

EXPERIMENTAL STUDY OF FLAMESPREADING PROCESSES IN 155-MM, XM216 MODULAR PROPELLING CHARGES

CARL R. RUTH
THOMAS C. MINOR

JUNE 1990

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE June 1990

3. REPORT TYPE AND DATES COVERED Final Mar - Sep 85

4. TITLE AND SUBTITLE

Experimental Study of Flamespreading Processes in 155-mm, XM216 Modular Propelling Charges

5. FUNDING NUMBERS

P: 1M463628D007

6. AUTHOR(S)

Carl R. Ruth and Thomas C. Minor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

USA Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

BRL-MR-3840

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The 155-mm, XM216 is a modular, combustible-cased, stick-propellant charge developed by the Armament Research, Development and Engineering Center (ARDEC) and recently type classified to provide the Zones 2-4 range coverage for the M198 Howitzer should another advanced propulsion option not be fielded. The propellant granulation and casing characteristics of the charge are unlike those of multiple-increment charges that have been fielded previously by the US Army. Past investigations of single-increment, combustible-cased, stick-propellant configurations which produced ballistic anomalies have indicated a substantial influence of particular igniter and charge attributes on ignition and flamespread, and by extrapolation, on the overall interior ballistic cycle. The charge developer, in order to assure that similar problems did not arise with the XM216, requested a characterization of the early, ignition and flamespread processes of the nearly final configuration charge.

Testing to provide such data was accomplished in the Ballistic Research Laboratory's 155-mm howitzer simulator. Firings were conducted for all zones at ambient and temperature extremes to characterize ignition transfer, flamespread, propellant-bed mobility, and pressure-wave development during the early portion of the interior ballistic cycle. From these and similar earlier tests, conclusions are drawn regarding the influence of initial charge temperature, ullage, propellant granulation, and charge casing on flamespread processes and the remainder of the ballistic cycle.

14. SUBJECT TERMS

Interior Ballistics, Pressure Waves, Modular Charges, Stick Propellant

15. NUMBER OF PAGES 40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

UNCLASSIFIED

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK.

LIST OF ILLUSTRATIONS

INTENTIONALLY LEFT BLANK.

LIST OF TABLES

INTENTIONALLY LEFT BLANK.

I. INTRODUCTION

The XM216 Propelling Charge, developed by the Armament Research, Development, and Engineering Center (ARDEC), was recently type classified to provide the Zones 2-4 range coverage in the 155-mm, M198 Howitzer, but will be produced only if the US Army does not either pursue the universal-increment charge for this howitzer or field the Advanced Field Artillery System (AFAS). If produced, the XM216 would become part of the family that includes the also recently type-classified, stand-alone, Zone 1, XM215 Propelling Charge and the standard, top-zone, M203A1 Propelling Charge.

A schematic of the XM216 is shown in Figure 1. The charge consists of individual modules: Zone 2, Module A; Zone 3, Module A plus one Module B; and Zone 4, Module A plus two Module Bs. A basepad consisting of 28 g of CBI with a 20-g black powder spot is placed only on the A Module. The propellant is M31A1 slotted-stick propellant, with the webs and lengths of the sticks being different between the A and B Modules. One of the main advantages of modular charge configurations is a rigid package consisting of interlocking components, thus facilitating automatic loading in future weapon systems. Furthermore, since the modular charge system will consist of a small number of discrete module types, the propelling charge corresponding to a desired performance level can be built up from the increments at firing time, rather than by discarding bags of propellant as is currently done with multizone artillery charges, resulting in a propellant and cost savings and a reduced logistics burden. New processing techniques allow for the use of additives, and the increased strength of loaded, rigidized combustible cartridge cases, as compared to bag charges, minimizes handling and transportation problems.

Let us now examine, with reference to Figure 2, some of the potential events in the early portion of the interior ballistic cycle with a combustible-cased, modular propelling charge. The output of a primer impinges on a basepad, and the burning basepad ignites the rear case wall of the module. Upon burn through of the rear case wall, the rear of the propellant bed is exposed to hot igniter gases and is heated to ignition. These hot

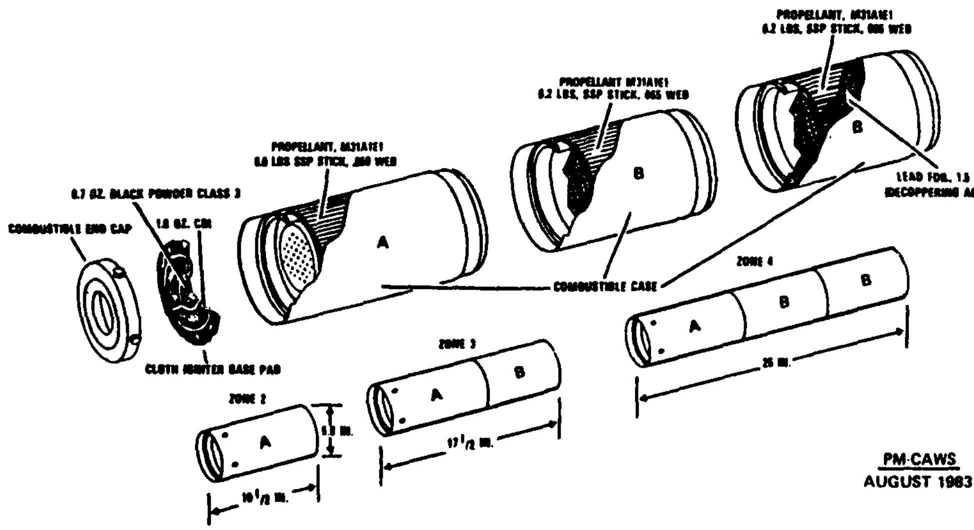


Figure 1. Schematic of 155-mm, XM216 Propelling Charge

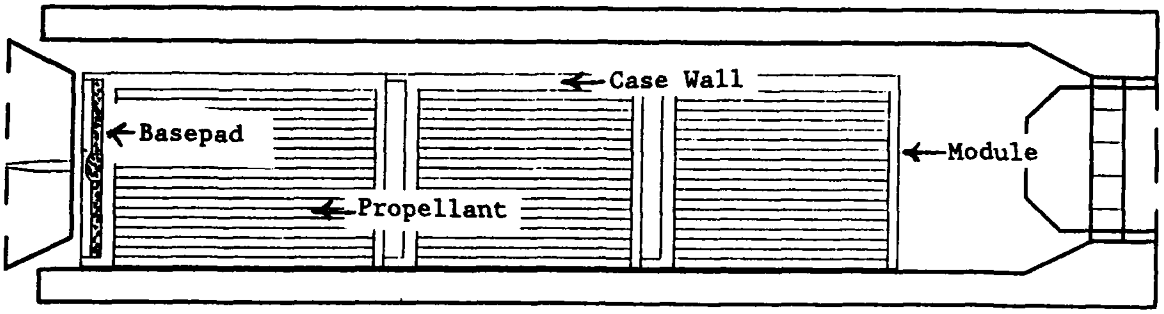


Figure 2. Phenomenology, Modular, Combustible-Case, Stick Propelling Charge

gases then join those from the igniter to produce flamespread through the charge. In the situation of granular propellant, resistance to the gas flow may lead to the formation of a pressure gradient in the propellant bed, and perhaps even movement of the solid phase, as we have previously discussed for bagged granular charges. However, with the use of stick propellant yielding a much smaller resistance to gas flow, essentially no pressure gradient is formed in the propellant bed, and we would not expect the solid phase to experience much movement. Yet, even with stick propellant, there will be substantial resistance to flow of the gases offered by the relatively impermeable interzone barriers presented by the case end walls, possibly leading to the propulsion of entire packages of propellant toward the projectile base. Complicating characterization of these phenomena, but perhaps leading to better ignition of the charge, the igniter gases may take the path of least resistance and flow into the annular ullage surrounding the charge, which almost certainly will be present in order to facilitate loading. We have noted such behavior in other combustible-cased charges employing stick propellant.[1] In this manner, the case may begin to burn along its entire length, and if the case collapses due to pressurization of the ullage, the propellant bed itself may be exposed to ignition gases along a substantial portion of its axial extent, promoting uniform ignition of the charge. Lastly, we cannot overlook the potential for fracture of the propellant. Such fracture may occur not only as a result of impact of a package of propellant on the projectile base but also due to attack of an overly brissant igniter on the rear of the charge. Furthermore, stick propellant may rupture due to a pressure differential established between the interior and exterior of the long grain. All of these processes serve to create additional, unprogrammed burning surfaces, which may lead to high local pressurization and the formation of pressure waves, should the natural flow channels presented by the stick propellant be obstructed.

---

[1]T.C. Minor and A.W. Horst, "Ignition Phenomena in Developmental, Stick-Propellant, Combustible-Cased, 155-mm, M203E2 Propelling Charges," ARBRL-TR-02568, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, July 1984.

Several previous experimental studies also helped to motivate this study. In an earlier test in the BRL 155-mm howitzer simulator with a granular, bagged, multizone charge with a relatively brissant base increment and slow-burning forward increments, it was found that the forward increment could be propelled toward the base of the projectile at a high speed.[2] While the XM216 Charge employs stick propellant, as noted above the barriers presented by the combustible case may present sufficient resistance to gas flow to result in propulsion of substantial quantities of propellant. In another study, it was seen that the method of ignition of the charge is often not as intended. In fact, rather than the igniter gases entering the propellant bed as desired, they have been seen to flow into the ullage, sometimes pressurizing it and severely compressing the case and propellant bed radially. Alteration of the ignition system to remove some of the blockages to igniter gas flow may correct the magnitude of the problem, but igniter gases still may not easily penetrate the end of the stick bundle.[3]

Earlier ARDEC testing with a candidate for the XM216 in which the forward modules were full of propellant showed the formation of pressure waves, while a candidate that was partially empty did not.[4] Testing of these two configurations in the BRL 155-mm Simulator showed that the full load of propellant supported the the combustible case wall such that it did not collapse during pressurization of the ullage surrounding the charge, keeping igniter gases away from the stick propellant bed. However, the partial propellant load provided no support to the combustible case, permitting it to collapse, allowing access of the ignition gases to the stick propellant, thus promoting more uniform ignition of the propellant bed.

History has shown us that problems with ammunition malfunctions, such as breech blows, originate in the early, ignition and flamespread portion of the interior ballistic cycle. The charge developer, ARDEC, naturally wished a complete characterization of the phenomenology of the charge before completing the charge development. ARDEC thus requested that the BRL fire a matrix of these charges in the simulator to characterize the early portion of the interior ballistic cycle.

---

[2]T.C. Minor, "Characterization of Ignition Systems for Bagged Artillery Charges," ARBRL-TR-02377, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1981.

[3]T.C. Minor and A.W. Horst, "Theoretical and Experimental Investigation of Flamespreading Processes in Combustible-Cased, Stick Propellant Charges," BRL-TR-2710, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, February, 1986.

[4]Private communication, R.S. Westley, ARDEC, Dover, NJ.

II. EXPERIMENTAL TECHNIQUES

Figure 3 depicts the apparatus used at the Ballistic Research Laboratory to conduct the experimental investigation. The illustration shows the mount with a clear plastic simulator for the 155-mm chamber in place. Although the mount also accepts higher-pressure, filament-wound fiberglass chambers, the plastic chambers were used in this study to a permit better view of the events transpiring within. The muzzle end of the chamber was closed by a projectile seated in a section of gun tube machined to the dimensions of the M199 Cannon. The breech end of the chamber was closed by a spindle similar to the mushroom configuration of the M185 Cannon with the centrally venting primer spithole, housing three piezoelectric pressure transducers. An instrumented baseplate (Figure 4) was attached to the base of the projectile; it permitted two gas pressure, three total force, and two acceleration measurements at the projectile base.

Photographic data were recorded with two high-speed, 16-mm cameras. For each shot, one camera was mounted with a wide angle lens to record the overall aspects of the event and another used a telephoto lens to allow detailed examination of the critical base region of the charge. With all of the cameras, data were recorded at a framing rate of approximately 5000 pictures per second. One-kHz timing signals were placed on the films by electronic circuits internal to the cameras, and the firing fiducial (time at which the firing voltage is applied to the gun) was also placed on the films to aid in correlation of the film data with other data.

Flash radiography was used to monitor the behavior of the solid phase during the interior ballistic cycle. Two 300-kV X-ray heads were employed, aligned perpendicular to the chamber axis and sufficiently separated from each other to allow coverage of the entire chamber length. One image (a "static"

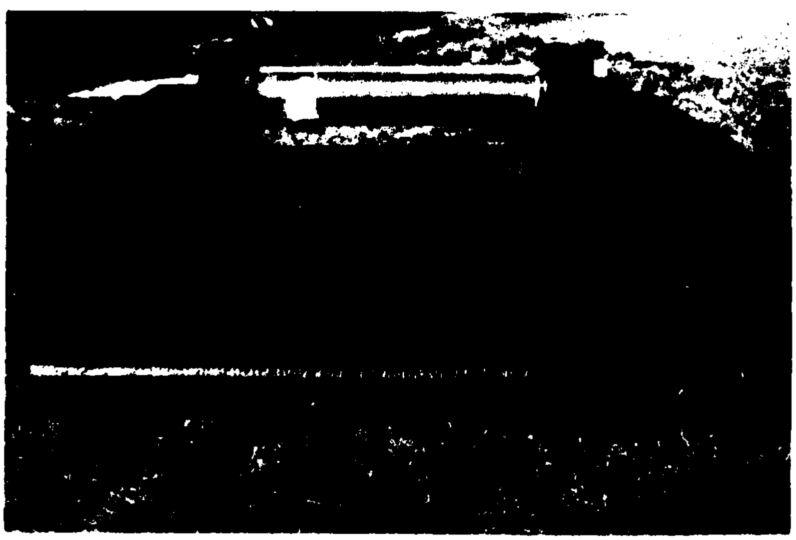


Figure 3. 155-mm Howitzer Simulator

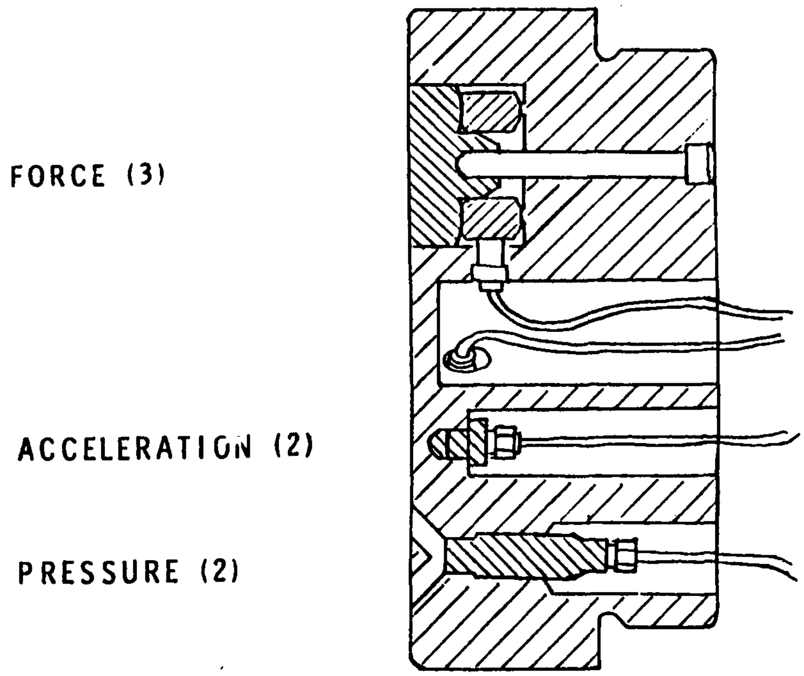


Figure 4. Instrumented Projectile Baseplate

shot) was taken of the charge in the chamber before firing, and a second, on a separate film, was recorded during the event by X-rays triggered at a predetermined spindle pressure (a "dynamic" shot). The X-ray film was protected from the blast of the disposable chamber by a wooden cassette, with the forward face composed of layers of air spaces and sacrificial wooden plates.

III. RESULTS AND DISCUSSION

Test firings were done in the BRL 155-mm howitzer simulator using XM216 Charges sent to us by the ARDEC, Dover, NJ. To maximize the amount of information from the limited number of charges available, firings were done at three different temperature and zone levels and in the order as indicated in Table 1. The matrix was weighted to provide more data at the upper-zone level while at the same time giving some indication of the behavior of the charge at the lower zones.

The measured maximum breech (spindle) pressure, P1, and forward chamber (projectile base) pressure, P2, the calculated pressure difference (P1 - P2), and the measured maximum charge motion before chamber rupture, from both film and X-ray records, are listed in Table 2. Also listed are the times when pertinent events occurred.

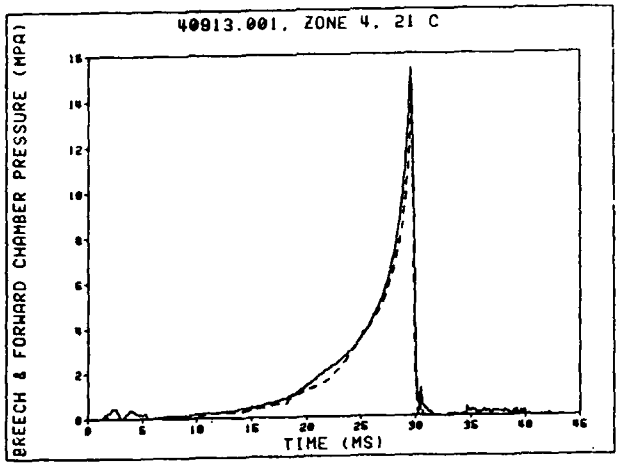
Table 1. Test Matrix

Charge	Zone	Temperature (°C)	Number of Rounds
XM216	4	21	2
	3		1
	2		1
XM216	4	63	2
	3		1
	2		1
XM216	4	-53	2
	3		1
	2		1

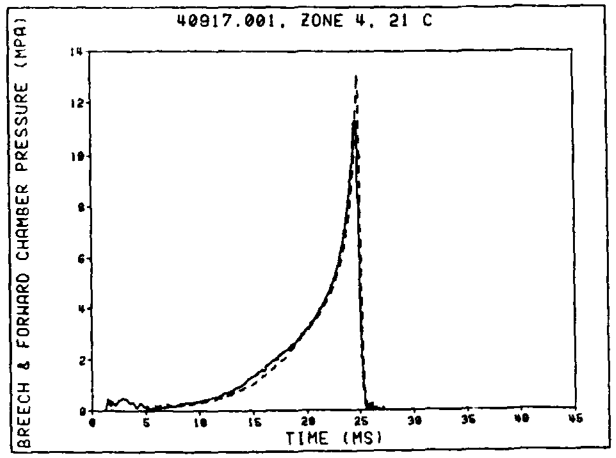
Figures 5, 6, and 7 are plots, respectively, of all the pressure-time traces for ambient (21 °C), hot (63 °C) and cold (-53 °C) firings at the Zone 2 (Module A), the Zone 3 (Modules A and B) and the Zone 4 (Modules A, B, and B) levels. For clarity in discussing module movement in the Zone 4 charge, the Module B closest to the projectile will be referred to as Module B', thus making the Zone 4 charge consist of a Module A, B, and B'. In all the plots of pressure, P1 is a solid line and P2 is a dotted line. In order to better clarify the events occurring during the ignition and early combustion process, one of the Zone 4 charges fired at 21 °C and 63 °C and both of the Zone 4 charges fired at -53 °C will be examined in detail. Ignition and combustion characteristics of the Zone 3 and 2 will be related to the Zone 4 firings. All times on the plots and events described from film and X-rays are related to the same zero time when the firing voltage was applied to the M52A3B1 electric detonating cap. For all firings there was approximately a 1-ms delay from the application of firing voltage until the M82 percussion primer functioned.

A. Firings at 21 °C

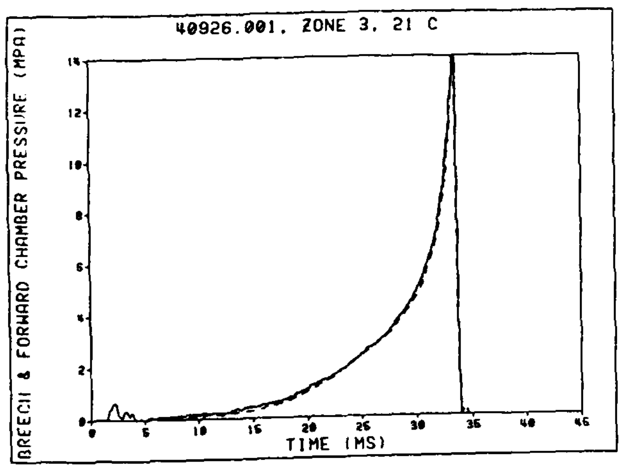
The pressure-time plot of Round 40913, Zone 4, ambient, with details obtained from the film record are shown in Figure 8 and Table 2; no X-rays were obtained for any of the ambient rounds. A schematic of the events taking place during flamespread is shown in Figure 9. At approximately 1 ms, the M82 primer ignited the basepad producing a 0.5-MPa pressure rise lasting for 4 ms. During this time interval, the rear cylindrical section of nitrocellulose (NC) contained within the basecap of Module A and the endcap enclosing the basepad were distorted (Figure 5). The gray ignition gases from the M82 and basepad pushed the rear of Module A to the top of the chamber breaking the rear top portion of the NC cylinder. Within 2 ms, the rear portion of Module A was well-ignited with bright orange-red gas covering the rear 3 cm of the chamber. By 8 ms, Module A was fully illuminated with luminous gases advancing forward into and around Modules B and B'. The rear upper portion of Module A broke off and burned separately. Parts of the Module A were pushed against the walls of the plastic chamber and continued to burn as the luminous front advanced forward into and around Modules B and B'. Within 11 ms, the entire Zone 4 charge was well-ignited even though the breech and forward chamber pressures were only 0.5 MPa. As the burning progressed, the forward



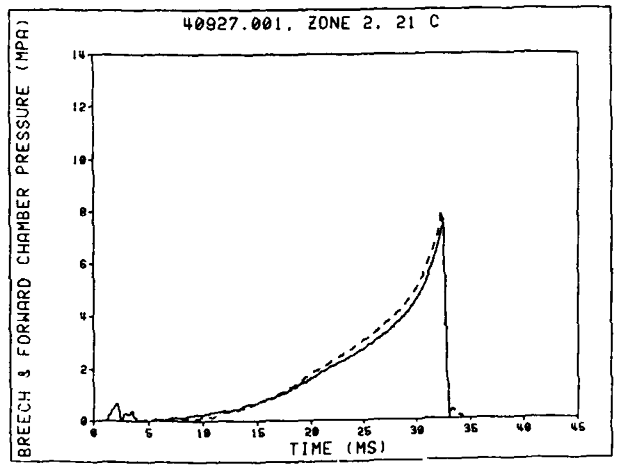
Zone 4



Zone 4

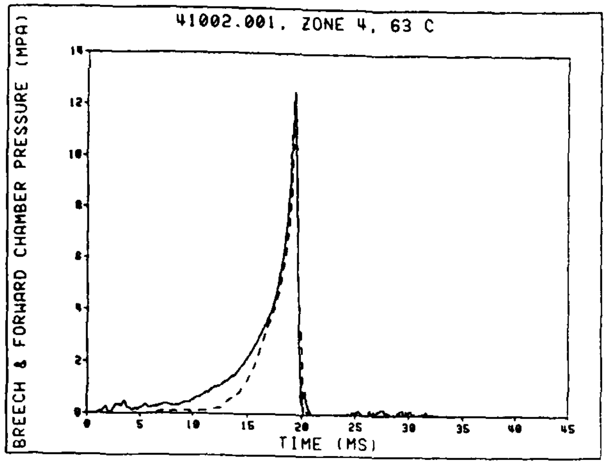


Zone 3

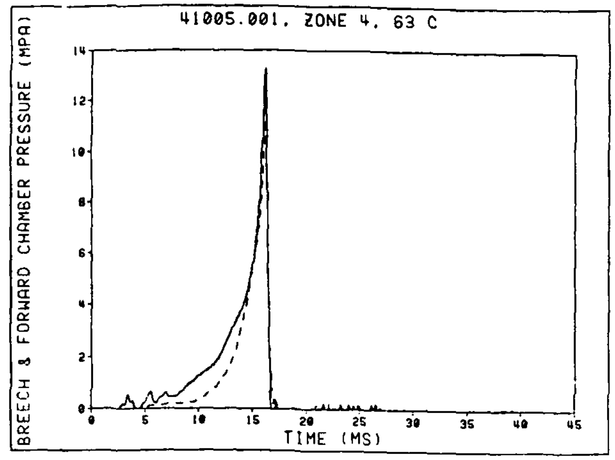


Zone 2

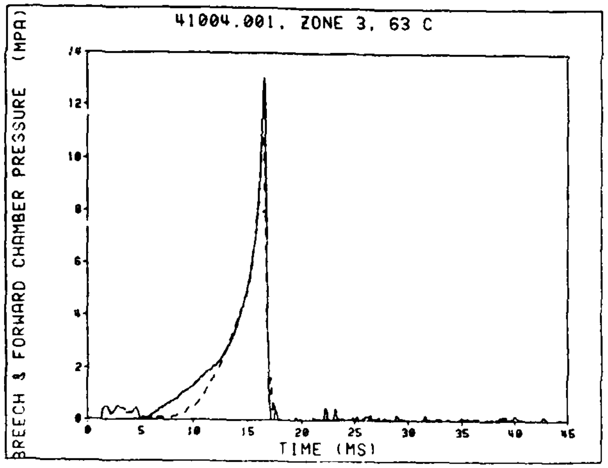
Figure 5. Breech and Forward Chamber Pressures, XM216 Propelling Charge, 21 $^{\circ}C$



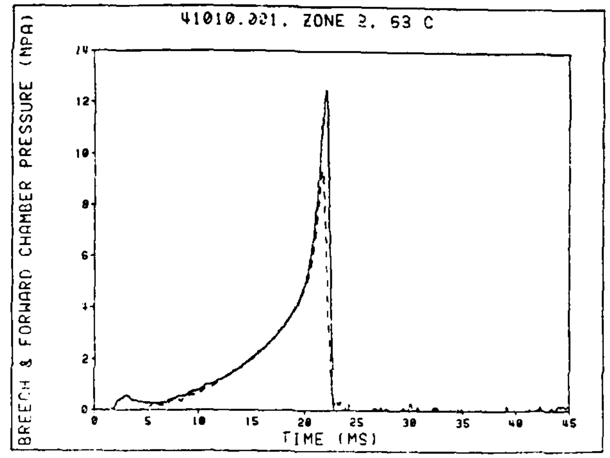
Zone 4



Zone 4

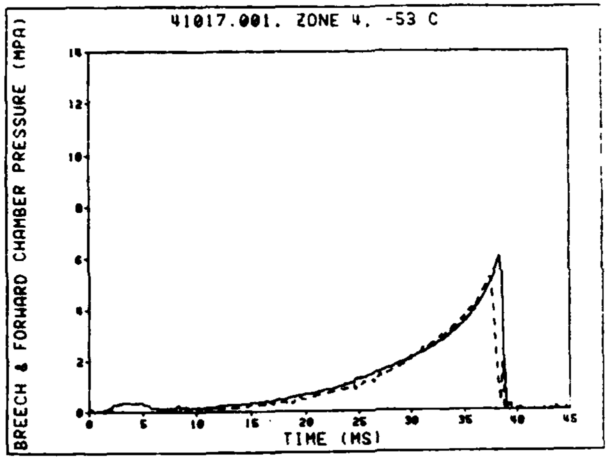


Zone 3

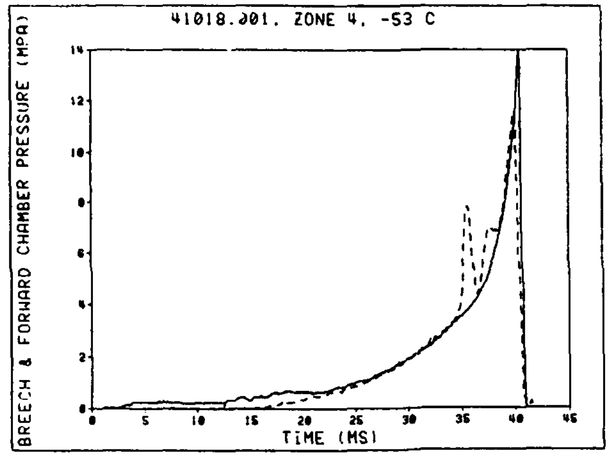


Zone 2

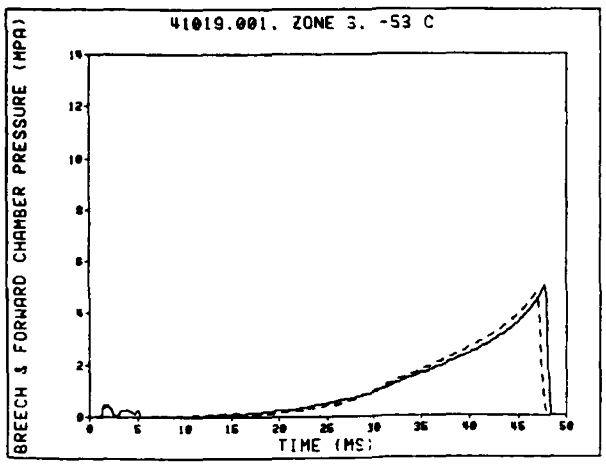
Figure 6. Breech and Forward Chamber Pressures, XM216 Propelling Charge, 63 °C



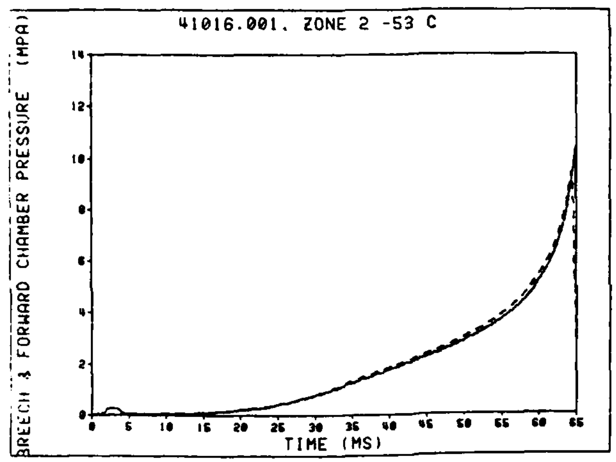
Zone 4



Zone 4



Zone 3



Zone 2

Figure 7. Breech and Forward Chamber Pressures, XM216 Propelling Charge, -53 °C

Table 2. Experimental Firing Data

Code	Zone	Temp (°C)	Maximum Pressure at Chamber Break: Breech (MPa)	Maximum Pressure at Chamber Break: Forward (MPa)	Total Event Time (ms)	Maximum Pressure Difference and Time of Occurrence: P1 - P2 (MPa)	Maximum Pressure Difference and Time of Occurrence: Time (ms)	Time to P1 1 MPa Pressure (ms)	Maximum Charge Movement: Film[1] (cm)	Maximum Charge Movement: X-ray[1] (cm) [MPa]
40913	4	21	15.4	13.8	29.5	0.4	21	18.7	1-2	X[2]
40917	4	21	11.4	12.9	24.6	0.3	16	14.1	1-2	X[2]
40926	3	21	14.9	14.3	33.3	0.1	15	19.6	0	X[2]
40927	2	21	7.6[2]	7.9[2]	33.0	-0.4	25	17.0	15	X[2]
41002	4	63	12.7	11.9	19.3	0.9	14	11.9	0	6 [8.9]
41005	4	63	13.5	11.7	16.6	0.9	14	9.3	2-4	6 [8.9]
41004	3	63	13.5	10.9	16.3	0.8	10	9.2	0	10 [8.9]
41010	2	63	12.5	9.4	21.8	0.1	10	11.0	16	16 [8.9]
41017	4	-53	6.1[2]	5.3[2]	37.9	0.2	26	23.5	14-16	X[2]
41018	4	-53	14.0	11.5	40.5	0.4	18	24.9	14-16	>16[3] [5.1]
41019	3	-53	5.1[2]	4.7[2]	47.7	-0.4	42	30.4	X	7 [5.1]
41016	2	-53	10.4	9.5	64.9	-0.3	60	32.5	25	25 [1.7]

Notes:

X - Lost.
1 - Charge motion determined from film and X-rays differs since film washed out well before chamber ruptured. The X-rays were recorded at the pressure indicated in brackets.
2 - Chamber broke early in the cycle.
3 - Charge moved forward to impact the projectile base; charge deformed to allow more movement than available in initial axial ullage.

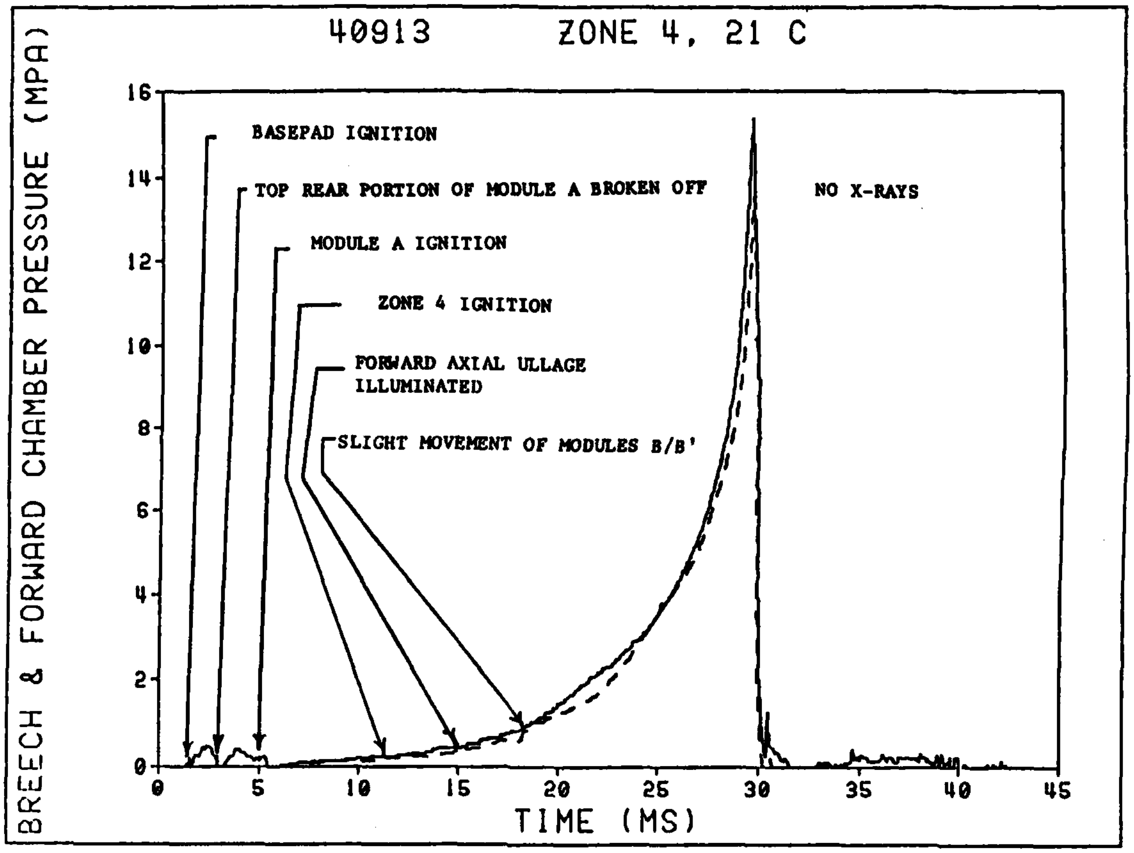


Figure 8. Annotated Breech and Forward Chamber Pressures, XM216 Propelling Charge, Zone 4, 21 °C, Round 40913

ullage in the chamber became illuminated (15 ms) as burning gases swirled into this region. This caused a 0.5-MPa pressure difference to develop from 18 ms to 25 ms after which the two pressures became coincident until the chamber broke at approximately 29 ms. During the entire combustion cycle, there was no indication of large movement of the charge. Just before the slight pressure gradient developed at 18 ms, Modules B and B' moved away slightly from the Module A component. Without X-rays, it was impossible to determine if the movement near chamber breakup was significant. With the exceptions that the peak chamber pressure was less and the corresponding event time shorter for the second Zone 4 shot, Round 40917, the events described above accurately reflect both Zone 4 firings.

The ignition and early combustion for the Zone 3, ambient charge, Round 40926, was as described for the Zone 4 round. Primer and basepad ignition times were essentially the same. As the ignition front and early combustion gases proceeded axially into and around the charge, pieces of the NC case were pushed against the chamber wall and proceeded to burn just as in the Zone 4 tests. As the gases flowed into the forward ullage, illuminating it with intense white, hot gas, no pressure gradient developed and no indication of module or charge motion was observed. The total event time was longer than for

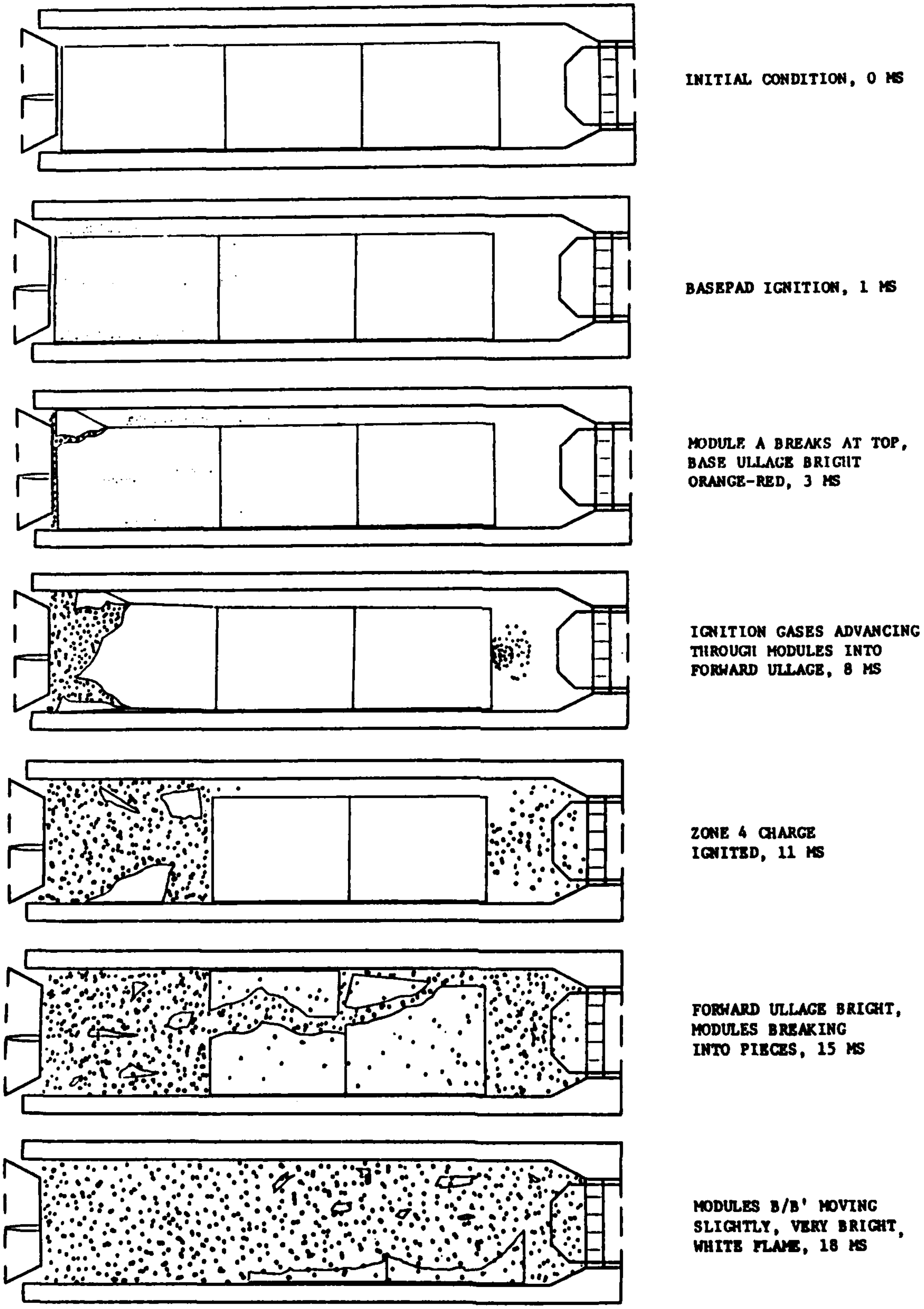


Figure 9. Schematic of Flamespread, XM216 Propelling Charge, Zone 4, 21 ^{o}C, Round 40913

the Zone 4 round previously described because, with the reduced density of loading, hot gases swirling into the larger forward ullage had less propellant and more ambient gas to heat during the combustion process.

For the ambient Zone 2 shot, Round 40927, ignition and early combustion were the same as the three previously described rounds. At approximately 8 ms, a small 0.25-MPa gradient developed corresponding to the charge moving forward 2-4 cm in the chamber. From 12 ms to 17 ms, the pressure traces indicated no gradient in the chamber. During this time, the charge moved forward approximately 15 cm. By 20 ms, a pressure gradient developed wherein the forward chamber gage became 0.5 MPa higher than the breech gage. This condition continued until the chamber ruptured. It is possible that the charge continued to move toward the projectile, but since the film was washed out by intense, white gases and X-rays were not obtained, further charge movement could not be verified. Since the force gages in the projectile base showed only gas response and not propellant impact, the extent of the charge movement was probably less than the space available in the forward axial ullage. The event time was the same as the Zone 3 firing because the chamber ruptured at a low 8 MPa rather than at the expected 11-12 MPa.

B. Firings at 63 °C

The pressure-time plots of Round 41002, Zone 4, hot, with details obtained both from film and X-ray are shown in Figure 10 and the data in Table 2. All four rounds in this series obtained, approximately, the same peak pressure before chamber rupture and X-rays recorded the charge motion just prior to rupture. At 1 ms, the M82 primer functioned. Within 2 ms, the basepad was well ignited causing a pressure rise of 0.50 MPa. Unlike the ambient rounds, the initial ignition pressure (Figure 10) did not decay to nothing before ignition of the main charge, but only decayed to 0.25 MPa. Then very quickly the pressure increased as the main charge ignited. By 9 ms, Module A was fully ignited and there was intense yellow light in the ullage at the rear of the charge. During the same time, the breech pressure increased rapidly from 0.5 MPa at 9 ms to 1 MPa at 12 ms. The ullage between the charge and projectile became very bright as combustion gases flowed into this region. Ignition proceeded so rapidly that a forward pressure gradient developed as soon as the charge ignited at 5 ms until near chamber rupture at 19 ms. Just prior to chamber rupture, there was no indication of charge motion from the film record. By this time, the film was almost completely washed out from the hot combustion gases in the ullage surrounding the charge.

The X-ray was triggered at 8.9 MPa just prior to chamber rupture. It showed large axial movement for the propellant and the NC case (Figure 11). The propellant in Module A was propelled forward en masse through the front of the module, thus punching out a disc of NC. As the propellant moved forward, it moved Modules B and B' and their propellant forward as a unit into the chamber 6 cm. Parts of the NC case were visible throughout the chamber.

The ignition and early combustion for both the second Zone 4 charge, Round 41005, and the Zone 3 charge, Round 41004, as observed from the films were the same as just described. There was some indication, from the film records, of minimal charge motion for the second Zone 4 round, but none for the Zone 3 round. X-rays for these two rounds were triggered at 8.9 MPa as in the previous test. For the Zone 4 firing, the propellant again moved en masse through the front of the NC module. Most of the module remained at its

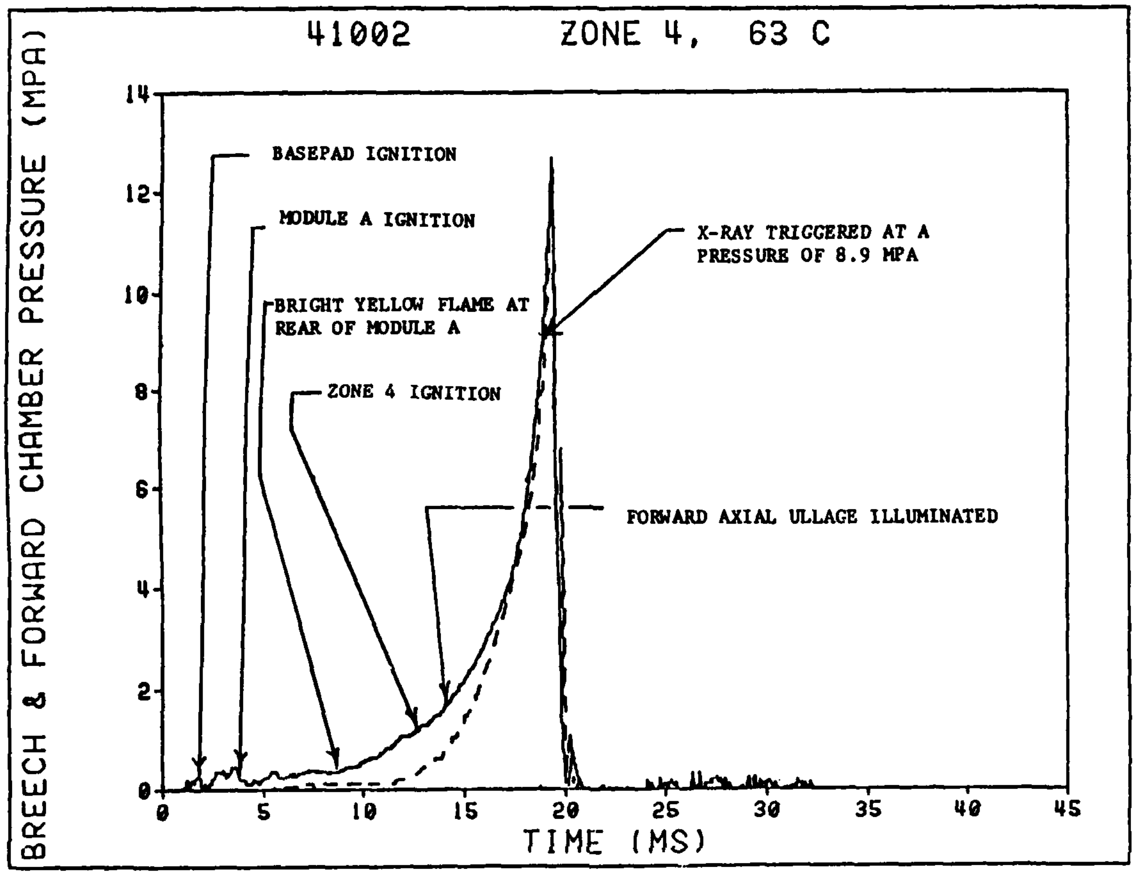


Figure 10. Annotated Breech and Forward Chamber Pressures, XM216 Propelling Charge, Zone 4, 63 °C, Round 41002

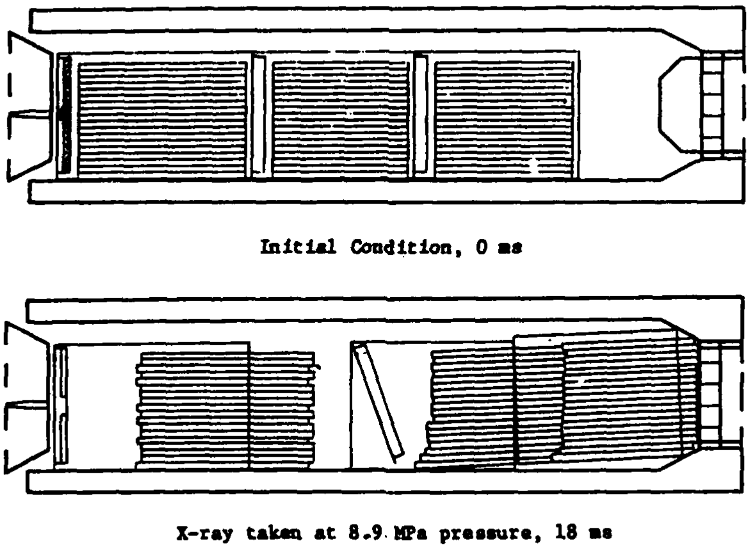


Figure 11. Schematic of X-ray, XM216 Propelling Charge, Zone 4, 63 °C, Round 41002

initial location in the chamber throughout the burning cycle. The force of the Module A propellant against Module B completely collapsed the 2-cm space between Modules B and B' and pushed the modules forward 6 cm in the chamber. This was larger than that noted on film; however, the X-ray event occurred at a time after events on film were washed out from the burning gases. The Zone 3 charge configuration when the X-ray triggered was similar to that of Round 41002, except that Module B moved 10 cm instead of 6 cm. In addition, the front of Module A and the front of Module B were also punched out by the force of the propellants from Modules A and propellant moving forward. In both tests, pieces of NC container could be seen throughout the chamber prior to rupture.

For Round 41010, Zone 2, hot, ignition and early combustion were similar to that described in the ambient Zone 2 round, albeit at a faster time. At 4 ms, the base region was well lit with gases starting to stream into the forward ullage. By 5 ms, the NC case had developed several radial cracks, hot gases were moving axially and radially forward through and around the charge lighting up the forward ullage, and there was some forward movement of NC. Unlike the previous three rounds, there was no pressure gradient. By 5 ms, the spindle and forward pressure gages were coincident which continued until the chamber ruptured. At 9 ms charge motion began, with a total movement of 16 cm before the chamber broke. One could see the Zone 2 module moving forward into the intense white light of the forward ullage. As before, the X-ray triggered at 8.9 MPa, recording the same charge motion as the film. Although the X-ray showed that the propellant moved forward approximately 16 cm, the detail was such that the condition of the NC module and parts could not be determined.

C. Firings at -53 °C

The pressure-time plot from Round 41017, Zone 4, cold, is given in Figure 12; other firing data are presented in Table 2. X-rays were not obtained because the chamber ruptured at a very low 6 MPa. At 1 ms, the basepad was ignited and dark smoke could be seen streaming forward along the radial ullage into the forward axial ullage. By 10 ms, the base region was very bright from ignition of Module A. As burning gases streamed around the charge into the forward ullage, the charge began to move forward at 13 ms. At 27 ms, the charge was still moving forward with the rear ullage becoming very luminous from the hot combustion gases. By 29 ms, the charge was completely forward against the projectile with all the ullage located between the spindle and the charge. Burning continued in this manner until the chamber ruptured at 38 ms. The forward chamber gage initially was slightly less than breech pressure, but after the charge moved forward against the projectile at approximately 30 ms, the two pressure gages reversed with the forward chamber gage being higher than the breech gage.

For the second Zone 4, Round 41018, the initial ignition sequence was completely different from any other round in all three series. The pressure-time plot is shown in Figure 13 with both high-speed film and X-ray events indicated. At 2 ms, the spindle pressure rose to 0.25 MPa, indicating that the basepad had been ignited, even though the film record showed no smoke or flame present. As the rear of Module A broke circumferentially, it ballooned into the chamber, channeling all the igniter gases forward through the charge. No ignition gases were visible in the radial ullage. The pressure remained constant until 12 ms when it slowly began to increase. The forward chamber

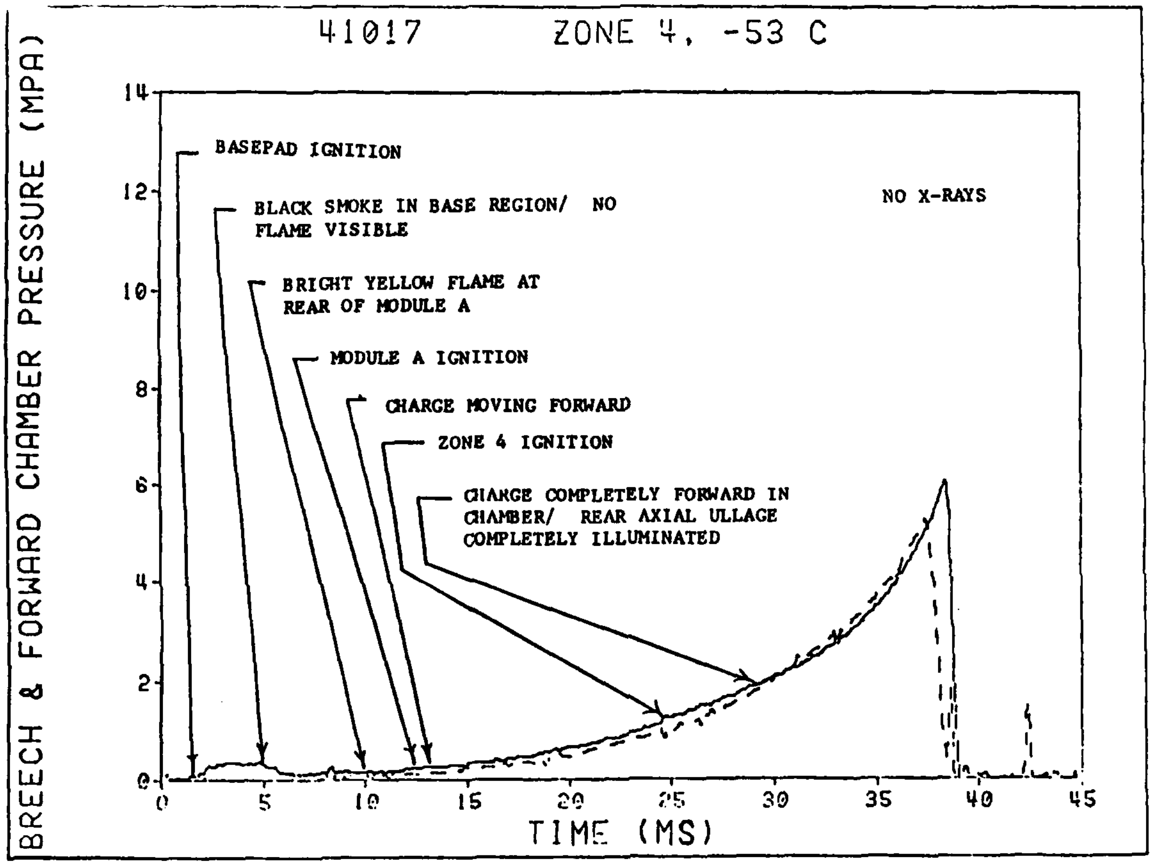


Figure 12. Annotated Breech and Forward Chamber Pressures, XM216 Propelling Charge, Zone 4, -53 °C, Round 41017

pressure gage showed no response until 16 ms. At 18 ms into the event, flame was present at the interface of Modules A and B. The flame began to spread axially both toward the projectile and the spindle. By 25 ms, when the forward chamber pressure was coincident with breech pressure, all three modules were burning. At 35 ms, the charge started moving forward into the projectile base and was still moving at 37 ms when the intense white flame washed out the film. At 35 ms, the forward chamber pressure-time trace indicated a sharp pressure pulse, suggesting that the charge moved forward at high velocity. This pulse, which was also noted by the force gage (not shown), damped out rapidly with the two chamber pressure traces being coincident before chamber rupture. That the gas-pressure gage responded similarly to the force gage is likely an artifact of the design of the gage block, in that a column of gas was trapped between the front of the charge and the recessed gas-pressure gage face. Although the film record of the ignition sequence appeared to be different from the first, Zone 4, cold firing, neither the total event time nor the time to pressurize the chamber to 1 MPa were different. Apparently, the ignition gases from the basepad were transmitted internally through the Module A component to the interface of Modules A and B with propellant burning inside the NC containers hidden from the view of the camera.

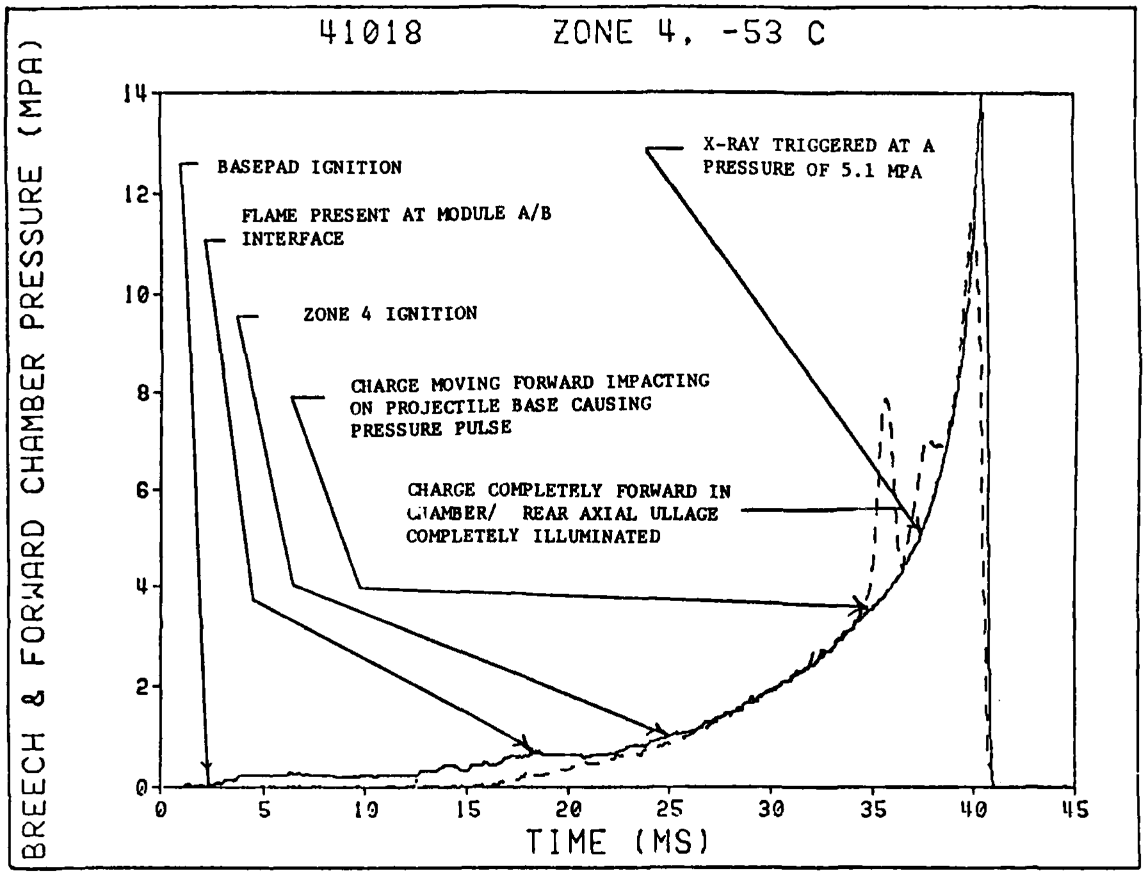


Figure 13. Annotated Breech and Forward Chamber Pressures, XM216 Propelling Charge, Zone 4, -53 °C, Round 41018

The X-ray for this Zone 4 firing, which was triggered fortuitously at 5 MPa when the pressure pulse occurred on the pressure trace, showed substantial charge motion. Module A propellant was propelled forward through the front of its NC enclosure with sufficient velocity to push both Modules B and B' forward into the projectile base. The 2-cm spaces at both of the interfaces were eliminated, the propellant from Module B' was tightly formed around the projectile base, and propellant from all three modules was axially compressed and radially expanded, so that no radial ullage existed around the forward portion of the charge. Most of the Module A container remained in its original location in the chamber.

The Zone 3 firing, Round 41019, was similar to the first cold Zone 4 firing in that the chamber broke early at 5 MPa. No film record was obtained for the firing. From the pressure-time traces, ignition of the basepad occurred at 2-3 ms after which both the breech and forward chamber pressures increased with minimal difference. By 30 ms, the forward chamber gage started to show a larger pressure than the breech gage and continued to do so until the chamber broke at 47 ms. Just prior to chamber rupture, the X-ray

triggered at 5.1 MPa. The X-ray indicated that Module B was propelled forward by Module A about 7 cm. The charge, burning in the forward section of the chamber, could account for the shift in the pressure traces.

The Zone 2 firing, Round 41016, was similar to the Zone 3 firing. After basepad ignition at 1-3 ms, the two coincident pressure traces remained at a low 0.1 MPa until 15 ms after which they both increased together. At 35 ms, the forward chamber pressure became slightly higher than the breech pressure and remained so until the chamber ruptured. During the 15 ms when the pressure was less than 0.1 MPa, most of the ignition and early charge motion occurred. At 7 ms, the rear portion of the module holding the basepad was burning rapidly with an intense flame and the charge was beginning to move forward. By 10 ms, the charge was well-lit with gases swirling around the radial ullage into the forward portion of the chamber. By 17 ms, the forward ullage was well-lit and the charge was continuing to move forward; this movement continued until the chamber broke at 65 ms. The X-ray triggered at 1.7 MPa, which occurred at about the time when the forward chamber pressure became larger than the breech pressure. The X-ray showed that the Module A propellant had moved 25 cm forward into the chamber as a mass. Unlike the other rounds, the propellant did not punch through the NC container, leaving the container in its original position in the chamber. In this firing, the NC cylinder was propelled into the forward section of the chamber well ahead of the propellant while parts of the basecap and endcap were left in the rear of the chamber.

IV. CONCLUSIONS

Within the constraints of a limited number of firings, we have examined the effects of conditioning temperature and charge zone levels on the flamespread portion of the interior ballistic cycle in the 155-mm, XM216 Charge. To answer the question posed by the charge designer, ARDEC, no obvious detrimental effects on the ignition and early combustion processes were observed for any of the three zones comprising the XM216 Charge at any of the three temperatures tested even though there was substantial separation between modules and between propellant and case at very low chamber pressures. The observed rapid pressurization and coincident breech and projectile base pressures just prior to chamber rupture suggest no propensity for the development of large pressure waves later in the ignition cycle. A cautionary note must be raised however, by the impact of the bundle of stick propellant on the base of the projectile at the cold conditioning temperature. While we saw no evidence of gross grain breakup in the high-speed films or flash X-rays, the possibility exists that some microscopic damage was imparted to the propellant, which might result in unprogrammed burning surface, leading to higher pressures that were beyond the range of the simulator tests performed.

Consistent with earlier tests with combustible-cased, stick propellant charges, we have seen that ignition and flamespread processes are probably not those which the charge designer, or even the charge design community, might expect. Once again, we have noted the great influence of the relative impermeability and mechanical strength of the packaging containers on the flamespreading path. We have noted the preferential flow of igniter gases into the ullage surrounding the charge rather than into the charge itself, the lack of well-defined flamespread within the stick propellant bed, and the movement of entire packages of propellant. We should emphasize, however, that

not all the resistance to gas entry into the main charge results from the barrier imposed by the combustible case. While natural flow channels within the bundle of sticks offer little resistance to the axial flow of gases, entrance conditions at the end of a stick bundle can provide quite an impediment to the entering gases, as evidenced by the movement of whole increments of the stick propellant outside of the modular case. The challenge to the charge design community is to exploit these perhaps non-intuitive aspects of the flamespread process to produce safe and reliable propelling charges.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Mr. Scott Westley, ARDEC, Dover, NJ for supplying the XM216 Propelling Charges used in the tests, to Messrs. J. Bowen, J. Hewitt, and J. Stabile, who conducted the test firings and recorded the data, and to Mr. A. Koszoru, who prepared artwork for this report.

REFERENCES

1. T.C. Minor and A.W. Horst, "Ignition Phenomena in Developmental, Stick-Propellant, Combustible-Cased, 155-mm, M203E2 Propelling Charges," ARBRL-TR-02568, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, July 1984.

2. T.C. Minor, "Characterization of Ignition Systems for Bagged Artillery Charges," ARBRL-TR-02377, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1981.

3. T.C. Minor and A.W. Horst, "Theoretical and Experimental Investigation of Flamespreading Processes in Combustible-Cased, Stick Propellant Charges," BRL-TR-2710, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, February, 1986.

4. Private communication, R.S. Westley, ARDEC, Dover, NJ.

No of Copies	Organization
1	Office of the Secretary of Defense OUSD(A) Director, Live Fire Testing ATTN: James F. O'Bryon Washington, DC 20301-3110
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQDA (SARD-TR) WASH DC 20310-0001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
2	Commander US Army, ARDEC ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory US Army, ARDEC ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000
1	Commander US Army Aviation Systems Command ATTN: AMSAV-DACL 4300 Goodfellow Blvd. St. Louis, MO 63120-1798

No of Copies	Organization
1	Director US Army Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099
1	Commander US Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-TSL (Technical Library) Warren, MI 48397-5000
1	Director US Army TRADOC Analysis Command ATTN: ATAA-SL White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TD
3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
1	Dir, VLAMO ATTN: AMSLC-VL-D

No. of Copies	Organization
1	Commander USA Concepts Analysis Agency ATTN: D. Hardison 8120 Woodmont Avenue Bethesda, MD 20014-2797
1	C.I.A. 01R/DB/Standard Washington, DC 20505
1	US Army Ballistic Missile Defense Systems Command Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807-3801
1	Chairman DoD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Avenue Alexandria, VA 22331-0600
1	Commander US Army Materiel Command ATTN: AMCPM-GCM-WF 5001 Eisenhower Avenue Alexandria, VA 22333-5001
1	Commander US Army Materiel Command ATTN: AMCDE-DW 5001 Eisenhower Avenue Alexandria, VA 22333-5001
4	Project Manager Autonomous Precision-Guided Munition (APGM) US Army, ARDEC ATTN: AMCPM-CW AMCPM-CWW AMCPM-CWS, M. Fisette AMCPM-CWA-S, R. DeKleine Picatinny Arsenal, NJ 07806-5000
2	Project Manager Production Base Modernization Agency ATTN: AMSMC-PBM, A. Siklosi AMSMC-PBM-E, L. Laibson Picatinny Arsenal, NJ 07806-5000
3	PEO-Armaments Project Manger Tank Main Armament Systems ATTN: AMCPM-TMA, K. Russell AMCPM-TMA-105 AMCPM-TMA-120 Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-AEE Picatinny Arsenal, NJ 07806-5000
8	Commander US Army, ARDEC ATTN: SMCAR-AEE-B, A. Beardell B. Brodman D. Downs S. Einstein S. Westley S. Bernstein C. Roller J. Rutkowski Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-AES, S. Kaplowitz D. Spring Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-HFM, E. Barrieres SMCAR-CCH-V, C. Mandala Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-FSA-T, M. Salsbury Picatinny Arsenal, NJ 07806-5000
1	Commander, USACECOM R&D Technical Library ATTN: ASQNC-ELC-I-T, Myer Center Fort Monmouth, NJ 07703-5301

No. of Copies	Organization
1	Commander US Army Harry Diamond Laboratories ATTN: SLCHD-TA-L 2800 Powder Mill Rd Adelphi, MD 20783-1145
1	Commandant US Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360
1	Project Manager US Army Tank-Automotive Command Improved TOW Vehicle ATTN: AMCPM-ITV Warren, MI 48397-5000
2	Program Manager US Army Tank-Automotive Command ATTN: AMCPM-ABMS, T. Dean Warren, MI 48092-2498
1	Project Manager US Army Tank-Automotive Command Fighting Vehicle Systems ATTN: AMCPM-BFVS Warren, MI 48092-2498
1	President US Army Armor and Engineer Board ATTN: ATZK-AD-S Fort Knox, KY 40121-5200
1	Project Manager US Army Tank-Automotive Command M-60 Tank Development ATTN: AMCPM-ABMS Warren, MI 48092-2498
1	Commander US Army Training and Doctrine Command ATTN: ATCD-MA, MAJ Williams Fort Monroe, VA 23651
2	Director US Army Materials Technology Laboratory ATTN: SLCMT-ATL Watertown, MA 02172-0001

No. of Copies	Organization
1	Commander US Army Research Office ATTN: Technical Library P. O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander US Army Belvoir Research and Development Center ATTN: STRBE-WC Fort Belvoir, VA 22060-5006
1	Director US Army TRAC-Ft Lee ATTN: ATRC-L (Mr. Cameron) Fort Lee, VA 23801-6140
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
1	Commandant US Army Special Warfare School ATTN: Rev and Tng Lit Div Fort Bragg, NC 28307
3	Commander Radford Army Ammunition Plant ATTN: SMCAR-QA/HI LIB Radford, VA 24141-0298
1	Commander US Army Foreign Science and Technology Center ATTN: AMXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Technical Library Washington, DC 20360

No. of Copies	Organization
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg Washington, DC 20375
1	Naval Research Laboratory Technical Library Washington, DC 20375
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
2	Commandant US Army Field Artillery Center and School ATTN: ATSF-CO-MW, B. Willis Ft. Sill, OK 73503-5600
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217-9999
3	Commandant US Army Armor School ATTN: ATZK-CD-MS, M. Falkovitch Armor Agency Fort Knox, KY 40121-5215
2	Commander US Naval Surface Warfare Center ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640-5000
4	Commander Naval Surface Warfare Center ATTN: Code 240, S. Jacobs Code 730 Code R-13, K. Kim R. Bernecker Silver Spring, MD 20903-5000
2	Commanding Officer Naval Underwater Systems Center ATTN: Code 5B331, R. S. Lazar Technical Library Newport, RI 02840

No. of Copies	Organization
5	Commander Naval Surface Warfare Center ATTN: Code G33, J. L. East W. Burrell J. Johndrow Code G23, D. McClure Code DX-21 Technical Library Dahlgren, VA 22448-5000
3	Commander Naval Weapons Center ATTN: Code 388, C. F. Price Code 3895, T. Parr Information Science Division China Lake, CA 93555-6001
1	Program Manager AFOSR Directorate of Aerospace Sciences ATTN: L. H. Caveny Bolling AFB Washington, DC 20332-0001
5	Commander Naval Ordnance Station ATTN: L. Torreyson T. C. Smith D. Brooks W. Vienna Technical Library Indian Head, MD 20640-5000
1	AL/TSTL (Technical Library) ATTN: J. Lamb Edwards AFB, CA 93523-5000
1	AFATL/DLYV Eglin AFB, FL 32542-5000
1	AFATL/DLXP Eglin AFB, FL 32542-5000
1	AFATL/DLJE Eglin AFB, FL 32542-5000
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22 Library Section Houston, TX 77054
1	AFELM, The Rand Corporation ATTN: Library D 1700 Main Street Santa Monica, CA 90401-3297

No. of Copies	Organization
3	AAI Corporation ATTN: J. Herbert J. Frankle D. Cleveland P. O. Box 126 Hunt Valley, MD 21030-0126
1	Aerojet Ordnance Company ATTN: D. Thatcher P.O. Box 296 Azusa, CA 91702
1	Aerojet Solid Propulsion Company ATTN: P. Micheli Sarcramento, CA 96813
1	Atlantic Research Corporation ATTN: M. King 5390 Cherokee Avenue Alexandria, VA 22312-2302
4	AL/LSCF ATTN: J. Levine L. Quinn D. Williams T. Edwards Edwards AFB, CA 93523-5000
1	AVCO Everett Research Laboratory ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149-5936
2	Calspan Corporation ATTN: C. Murphy P. O. Box 400 Buffalo, NY 14225-0400
1	General Electric Company Armament Systems Department ATTN: M. J. Bulman 128 Lakeside Avenue Burlington, VT 05401-4985
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616-3799
1	Hercules, Inc. Allegheny Ballistics Laboratory ATTN: William B. Walkup P. O. Box 210 Rocket Center, WV 26726

No. of Copies	Organization
1	Hercules, Inc. Radford Army Ammunition Plant ATTN: J. Pierce Radford, VA 24141-0299
3	Lawrence Livermore National Laboratory ATTN: L-355, A. Buckingham M. Finger L-324, M. Constantino P. O. Box 808 Livermore, CA 94550-0622
1	Olin Corporation Badger Army Ammunition Plant ATTN: R. J. Thiede Baraboo, WI 53913
1	Olin Corporation Smokeless Powder Operation ATTN: D. C. Mann P. O. Box 222 St. Marks, FL 32355-0222
1	Paul Gough Associates, Inc. ATTN: Dr. Paul S. Gough 1048 South Street Portsmouth, NH 03801-5423
1	Physics International Company ATTN: Library, H. Wayne Wampler 2700 Merced Street San Leandro, CA 98457-5602
1	Princeton Combustion Research Laboratory, Inc. ATTN: M. Summerfield 475 US Highway One Monmouth Junction, NJ 08852-9650
2	Rockwell International Rocketdyne Division ATTN: BA08, J.E. Flanagan J. Gray 6633 Canoga Avenue Canoga Park, CA 91303-2703
3	Thiokol Corporation Huntsville Division ATTN: D. Flanigan Dr. John Deur Technical Library Huntsville, AL 35807

No. of Copies	Organization
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Technical Library P. O. Box 241 Elkton, MD 21921-0241
1	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Highway East Amherst, NY 14501-0305
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 84029
1	Battelle Memorial Institute ATTN: Technical Library 505 King Avenue Columbus, OH 43201-2693
1	Brigham Young University Department of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601
1	California Institute of Technology 204 Karman Laboratory Main Stop 301-46 ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91109
1	California Institute of Technology Jet Propulsion Laboratory ATTN: L. D. Strand, MS 512/102 4800 Oak Grove Drive Pasadena, CA 91109-8099
1	University of Illinois Department of Mechanical/Industrial Engineering ATTN: H. Krier 144 MEB; 1206 N. Green Street Urbana, IL 61801-2978
1	University of Massachusetts Department of Mechanical Engineering ATTN: K. Jakus Amherst, MA 01002-0014

No. of Copies	Organization
1	University of Minnesota Department of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55414-3368
1	Case Western Reserve University Division of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: B.T. Zim E. Price W.C. Strahle Atlanta, GA 30332
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616-3896
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707-0690
1	Massachusetts Institute of Technology Department of Mechanical Engineering ATTN: T. Toong 77 Massachusetts Avenue Cambridge, MA 02139-4307
1	Pennsylvania State University Applied Research Laboratory ATTN: G.M. Faeth University Park, PA 16802-7501
1	Pennsylvania State University Department of Mechanical Engineering ATTN: K. Kuo University Park, PA 16802-7501
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47907-1199

No. of Copies	Organization
1	SRI International Propulsion Sciences Division ATTN: Technical Library 333 Ravenwood Avenue Menlo Park, CA 94025-3493
1	Rensselaer Ploytechnic Institute Department of Mathematics Troy, NY 12181
2	Director Los Alamos Scientific Laboratory ATTN: T3, D. Butler M. Division, B. Craig P. O. Box 1663 Los Alamos, NM 87544
1	General Applied Sciences Laboratory ATTN: J. Erdos 77 Raynor Avenue Ronkonkama, NY 11779-6649
1	Battelle PNL ATTN: Mr. Mark Garnich P. O. Box 999 Richland, WA 99352
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Castle Point Station Hoboken, NJ 07030-5907
1	Rutgers University Department of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	University of Southern California Mechanical Engineering Department ATTN: 0HE200, M. Gerstein Los Angeles, CA 90089-5199
2	University of Utah Department of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112-1194

No. of Copies	Organization
1	Washington State University Department of Mechanical Engineering ATTN: C. T. Crowe Pullman, WA 99163-5201
1	Honeywell, Inc. ATTN: R. E. Tompkins MN38-3300 10400 Yellow Circle Drive Minnetonka, MN 55343
1	Science Applications, Inc. ATTN: R. B. Edelman 23146 Cumorah Crest Drive Woodland Hills, CA 91364-3710

Aberdeen Proving Ground

Cdr, CSTA
ATTN: STECS-LI, R. Hendricksen

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number BRL-MR-3840 Date of Report JUNE 1990

2. Date Report Received ______

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

CURRENT ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)

--FOLD HERE--

DEPARTMENT OF THE ARMY
Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066
OFFICIAL BUSINESS

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

POSTAGE WILL BE PAID BY ADDRESSEE

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-9989

--FOLD HERE--